Remote-Site Ambient Ozone Data Summary, 2018

Regions 2 and 4, US Forest Service

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Deadman Pass remote ozone monitoring site, Arapaho-Roosevelt National Forest, Colorado

Executive Summary:

- RMRS monitored 21 remote, mostly-rural sites for non-regulatory continuous surface ozone data in 2018. Six additional regulatory sites (five CASTNet sites, and one operated by a contractor to the San Juan NF) were included in the analyses. All of the CASTNet sites, the SJNF site, and five of the RMRS-operated sites collected year-round data; the others were deployed during the growing season. There were no changes in monitoring locations from the previous year.
- Nineteen of the 27 sites in this report recorded 4th-maximum 8-hour average readings that exceed the 2015 ozone National Ambient Air Quality Standard (NAAQS).
- The regulatory design value, the three-year average of 4th-maxima, was computed for most sites. Six of the 27 sites had values exceeding the NAAQS. USEPA have announced new nonattainment area designations in the Uintah Basin and Wasatch Front.
- Cumulative ozone exposure was assessed using the W126 metric. Areas with consistently high ozone exposure include the Front Range, Uintah Basin, and Wasatch Front. Pollutants from urban sources and industrial emissions frequently reach USFS lands in these areas, and vegetation should be monitored for signs of ozone damage.
- Wildfires produced large volumes of ozone precursors in 2018, emphatically raising ozone levels. Three wildfire events (Spring Creek and 416/Burro in Colorado, Carr/Mendocino Complex in California) created conditions during which the year's highest readings were observed.
- Data completeness stood at 88.7% network-wide, and 88.1% for RMRS and NFS-operated sites.
- Data for 2017 and 2018 were uploaded to the USEPA Air Quality System (AQS) in July 2019. Data were also provided to the Intermountain West Data Warehouse – Western Air Quality Study (IWDW-WAQS), and to Colorado Department of Public Health and Environment (CDPHE) and other interested parties.

I. Changes in the Regulatory Environment

EPA continued implementation of the 2015 ozone NAAQS (70 ppb) and issued a new nonattainment assessment in April 2018 (USEPA, 2018) using data collected in 2014-2016. Designations for states within and near the footprint of R2/R4 are listed below.

Colorado: All of the Denver metropolitan area counties, and parts of Larimer and Weld Counties remain in nonattainment. USEPA predicted that areas in/around Colorado Springs (El Paso County) would designated for nonattainment by 2018 (USEPA 2016), but this did not occur as of publication of the 2018 document. Additional monitoring data collected by the Colorado Department of Public Health and Environment (CDPHE) and USFS in El Paso County in 2018 are still being analyzed as of this writing. Mesa County (Grand Junction area) had also been predicted to be in nonattainment, but was not designated.

Utah: Two counties (Salt Lake, Davis) and portions of three more (Utah, Weber and Tooele) in Utah's Wasatch Front were determined to be in "marginal nonattainment" in USEPA's 2018 adjudication (USEPA 2019). Also, portions of two counties in northeastern Utah (Uintah, Duchesne) were also designated for marginal nonattainment. RMRS continued data collection at the Snowbird ski area in Salt Lake County and at Little Mountain near Vernal. There is also a CASTNet facility northeast of Vernal at Dinosaur National Monument, east of the Ashley NF boundary, which is included in this

year's report. A proposed rule (Federal Register 2019) addresses affected public, private, and tribal lands and industrial activities.

Nevada: USEPA's 2018 report determined the Las Vegas metropolitan area (Clark County) to be in nonattainment. The Spring Mountains NRA (Humboldt-Toiyabe NF) is in Clark County. North of Las Vegas, Whie Pine County was projected to be in nonattainment, but was not so designated.

California: Portions of two counties (Nevada, El Dorado) in eastern California are in nonattainment per the 2018 assessment. Although no R4 NFS lands are within the nonattainment areas, parts of the Humboldt-Toiyabe NF are immediately downwind.

Although USEPA predicted that most of the current nonattainment areas outside California would achieve attainment by 2025 (USEPA 2016), the additional designations in the 2018 report suggest that more progress will have to be made in curbing emissions in order to meet this expectation.

II. Network Performance, Changes and Updates for 2018

No new sites were established in 2018 (fig. 1, below), although one previously-decommissioned site, at Manitou Experimental Forest on the Pike-San Isabel NF, was reactivated for 2018. This was done at the request of CDPHE (see Regulatory Changes, above) to assist with ozone assessment near Colorado Springs. With the nonattainment designation of the northeastern Utah counties, analysis of ozone data from Dinosaur National Monument has been added to the five other CASTNet sites included in previous reports.

Two sites were decommissioned at the end of the 2018 monitoring season. Silt-Collbran and Flattops were located in close proximity to three other USFS sites (Ripple Creek Pass, Sunlight, McClure Pass) and one CDPHE site (Rifle). Analyses by the Intermountain West Data Warehouse (IWDW) indicated that ozone in the area covered by Silt-Collbran and Flattops could readily be modeled using data from surrounding sites. Data collection will continue at Sunlight year-round and seasonally at McClure and Ripple Creek Pass. Both of the decommissioned sites were serviced for several years by volunteer Andrea Holland (White River NF, retired), who continues to serve the Sunlight, Norwood, McClure Pass and Ripple Creek Pass sites. RMRS thanks Andrea for her diligence in helping provide high-quality data from central Colorado.

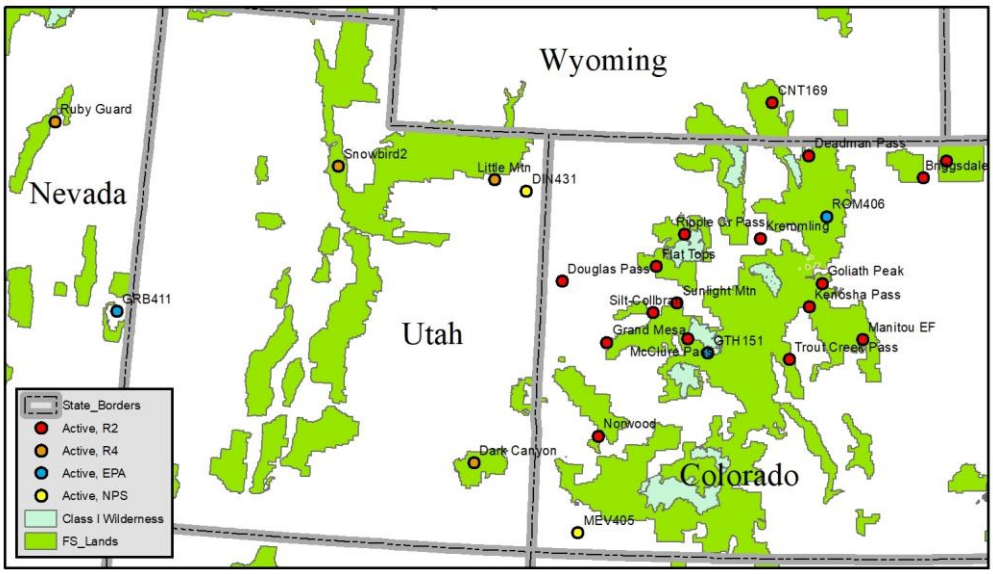

Fig. 1. RMRS ambient ozone data collection locations on and near R2/R4 forests, 2018.

Network-wide, data completeness stood at 88.7%, with USFS-operated sites at 88.1%. Both figures are similar to those in years past and represent an acceptable rate of data capture.

Most of the RMRS-maintained sites were audited by CDPHE field personnel during 2018, and several sites experienced calibration problems due to old, ineffective nafion tubing in the sample path. This problem made the machines sensitive to, and inaccurate during, periods of rapid changes in humidity, especially at and immediately after sunrise. The amount by which the affected data deviated could not be reliably determined, so no attempt was made to correct the data. The problem was eliminated for 2019 by replacement of all suspect nafion tubing.

The site at Ruby Guard Station, Nevada, was again plagued by power-supply problems. All of the site's equipment was removed in 2019 in anticipation of replacement for subsequent monitoring seasons, and the site should not experience future data losses due to this problem.

McClure Pass (Colorado) experienced a partial battery failure, but continued collecting daytime data via solar power.

Little Mountain (Utah) experienced a heavy rime-ice and wind event in February, and the site was inactive from early February through early April. The damaged instrumentation was replaced, and the site extensively upgraded in April and May of 2018. Ashley NF personnel assisted with this work.

The Dark Canyon site (Gooseberry Guard Station, Utah) experienced an unknown datalogger failure in mid-August. Subsequent diagnoses in the laboratory and at Campbell Scientific were inconclusive.

Two sites, Grand Mesa and Deadman, were not accessible until about a month past their usual installation dates.

Year-Round Sites	Forest	Begin Date	End Date	Data Completeness	Notes
Pawnee Buttes	PNG	1 Jan	31 Dec	92.0	
Briggsdale	PNG	1 Jan	31 Dec	87.7	
Kenosha Pass	PSINF	1 Jan	31 Dec	90.3	
Sunlight Mtn	WRNF	1 Jan	31 Dec	98.9	
Little Mtn	Ashley	1 Jan	31 Dec	69.9	Weather damage Feb-Apr
Centennial CASTNet	MBRNF	1 Jan	31 Dec	85.5	
RMNP CASTNet	RMNP	1 Jan	31 Dec	99.3	
Gothic CASTNet	GMUG	1 Jan	31 Dec	94.1	
GBNP CASTNet	GBNP	1 Jan	31 Dec	97.1	
Mesa Verde CASTNet	MVNP	1 Jan	31 Dec	92.1	
Shamrock	SJNF	1 Jan	31 Dec	83.8	
Seasonal Sites					
Deadman Pass	ARNF	5 Jul	21 Nov	66.2	Access difficulties, early season
Goliath Pk	ARNF	3 Jun	26 Oct	95.5	
Trout Cr Pass	PSINF	29 Apr	14 Oct	98.5	
Manitou EF	PSINF	29 Apr	15 Oct	96.6	
Kremmling	BLM	24 Apr	9 Oct	96.5	
McClure Pass	GMUG	28 Apr	14 Oct	87.0	Battery deficiency
Flattops	WRNF	30 May	7 Oct	91.7	
Ripple Cr Pass	WRNF	1 Jun	7 Oct	98.0	
Silt-Collbran	WRNF	1 Apr	14 Oct	93.2	
Grand Mesa	GMUG	31 May	14 Oct	79.1	Access difficulties, early season
Norwood	SJNF	31 Mar	11 Oct	94.0	
Douglas Pass	BLM	29 Mar	9 Oct	96.2	
Snowbird	WCNF	30 Mar	11 Oct	98.0	
Dark Canyon	MLSNF	27 Apr	10 Aug	65.3	Datalogger failure, late season
Ruby Guard	HTNF	26 Apr	28 Sep	68.1	Power failure

Table 1. 2018 Network performance

II. Data Summary:

	Average O_3 (ppb)		Daily 8-hour O_3 (ppb)				Cumulative O_3 (ppm-hr)	
Year-Round Sites	**Daytime**	**Overnight**	**Max**	**Date**	**4th Max**	**Date**	**Max W126****	**Period**
Pawnee Buttes	49.9	41.7	74.4	2 Aug	68.8	18 Jul	15.4	Jun-Aug
Briggsdale	51.0	28.4	79.8	2 Aug	70.3	24 Aug	16.9	Jun-Aug
Kenosha Pass	57.3	51.8	94.9	11 Jun	81.9	14 Jul	23.9	Jun-Aug
Sunlight Mtn	53.6	54.9	86.8	11 Jun	74.6	2 Aug	18.4	Jun-Aug
Little Mtn	59.1	57.2	86.3	11 Jun	74.6	23 Apr	24.5	May-Jul
Shamrock	54.0	44.4	73.1	24 May	71.7	7 Aug	16.1	May-Jul
Centennial CASTNet	53.3	52.4	75.3	11 Jun	70.0	9 Aug	13.6	Jun-Aug
RMNP CASTNet	53.8	46.0	91.8	11 Jun	74.1	10 Aug	18.1	Jun-Aug
Gothic CASTNet	53.5	40.7	88.9	11 Jun	69.3	27 May	15.6	May-Jul
GBNP CASTNet	52.2	48.4	73.3	4 Jul	71.1	2 Aug	13.9	May-Jul
Mesa Verde CASTNet*	53.8	49.9	75.9	6 Aug	72.1	21 Jul	13.5*	Apr-Jun
Dinosaur CASTNet	51.8	35.9	73.9	11 Jun	67.8	1 Aug	14.5	Jun-Aug
Seasonal Sites								
Deadman Pass*	55.8	56.2	79.3	10 Aug	75.0	31 Jul	15.8*	Jul-Sep
Goliath Pk	56.8	55.8	91.2	11 Jun	84.0	10 Jul	26.2	Jun-Aug
Trout Cr Pass	55.3	49.4	90.8	11 Jun	72.6	14 Jul	19.0	May-Jul
Manitou EF	55.1	31.8	81.0	2 Aug	76.3	12 Jun	21.7	Jun-Aug
Kremmling	49.0	25.3	86.8	11 Jun	67.3	18 Jul	10.6	May-Jul
McClure Pass	54.6	52.9	85.7	11 Jun	71.6	1 Aug	17.9	May-Jul
Flattops	51.6	54.3	83.1	11 Jun	69.7	2 Aug	11.8	Jun-Aug
Ripple Cr Pass	54.5	54.5	85.9	11 Jun	72.1	1 Aug	16.7	Jun-Aug
Silt-Collbran	55.2	50.2	85.8	11 Jun	70.9	6 Aug	19.2	Jun-Aug
Grand Mesa	53.1	53.9	78.0	11 Jun	67.3	19 Jun	13.9	Jun-Aug
Norwood	50.5	39.8	71.4	11 Jun	67.5	24 Jun	12.4	Jun-Aug
Douglas Pass	54.7	53.9	79.1	11 Jun	71.9	31 Jul	18.3	Jun-Aug
Snowbird	58.8	55.7	89.0	1 Aug	81.4	31 Jul	27.4	Jun-Aug
Dark Canyon	58.4	48.5	76.6	1 Aug	72.4	6 Aug	19.9*	May-Jul
Ruby Guard	51.8	49.0	78.5	24 Aug	69.5	20 Aug	12.3	Jun-Aug

Table 2: Summary statistics for all 2018 Sites. "Average O_3" is the mean of ozone readings between 8 a.m.-8 p.m. (Daytime) and 8 p.m.-8 a.m. (Overnight) for the entire growing season (April-September) . "Daily 8-hour O_3" reports the days on which the highest and 4th-highest 8-hour averages were recorded (see text for further explanation). Values in red (over 70 ppb) are contributory to NAAQS exceedance.

*indicates site where missing data precluded complete assessment; actual peak may have not have been observed. Deployment dates listed in Table 1.

**Statistic reflective of potential impact of long-term vegetation exposure; see discussion below.

III. Discussion:

The 2018 ozone monitoring data are a substantial departure from the long-term trend of decreasing surface ozone in the western US. **Nineteen of the 27 sites analyzed in this report experienced a fourth-maximum daily ozone value in excess of the 2015 ozone NAAQS.** This is a startling development, and is indicative of the need to continue to monitor

this pollutant and assess its effects on vegetation on national forests even when long-term data suggest a decreasing hazard. The 2018 observations indicated the highest ozone loading since monitoring on USFS lands began in 2006. Ozone levels in urban, rural and high-elevation locations were greatly elevated over the relatively benign concentrations observed in recent years. At the Kenosha Pass site, for example, daytime and overnight average concentrations during the growing season were elevated more than 5 ppb over 2017.

From a regulatory perspective, the most critical metric of ozone pollution is the three-year average of 4th-maxima, which USEPA uses to make determinations of 2015 NAAQS attainment. It was possible to compute this average for nearly all of the sites on the USFS network for the 2016-2018 frame (Table 3), and the very high peak ozone observations in 2018 pushed the 3-year average over the NAAQS at six sites.

Site	2016	2017	2018	3-Year Average
Pawnee Buttes	59.2	63.6	68.8	63.9
Briggsdale	65.6	64.1	70.3	66.7
Kenosha Pass	69.3	66.4	81.9	72.5
Sunlight Mtn	67.5	63.9	74.6	68.7
Little Mtn	62.0	67.9	74.6	68.2
Shamrock	65.3	66.3	71.7	67.8
Centennial CASTNet	65.9	66.8	70.0	67.6
RMNP CASTNet	69.8	67.1	74.1	70.3
Gothic CASTNet	62.6	65.6	69.3	65.8
GBNP CASTNet	63.5	65.1	71.1	66.6
Mesa Verde CASTNet	66.8	66.5	72.1	68.5
Dinosaur CASTNet	75.3	74.4	67.8	72.5
Deadman Pass	71.4	71.6	75.0	72.7
Goliath Pk	77.3	67.7	84.0	76.3
Trout Cr Pass	71.2	46.1	72.6	63.3
Kremmling	62.9	57.1	67.3	62.4
Manitou EF	No Data		76.3	
McClure Pass	63.6	62.3	71.6	65.8
Flattops	56.9	67.7	69.7	64.8
Ripple Cr Pass	No Data	67.9	72.1	
Silt-Collbran	64.6	67.0	70.9	67.5
Grand Mesa	62.7	65.5	67.3	65.2
Norwood	68.6	61.7	67.5	65.9
Douglas Pass	64.1	65.0	71.9	67.0
Snowbird	70.9	72.4	81.4	74.9
Dark Canyon	57.5	61.5	72.4	63.8
Ruby Guard	55.7	61.1	69.5	62.1

Table 3. Fourth-maximum daily values and three-year averages, 2016-2018.

There are two caveats for these figures, however. First, only the data from the CASTNet sites evaluated here are used by USEPA for NAAQS enforcement; the other sites are not considered regulatory sites. Second, the heavy precursor emissions from wildfires in 2018 resulted in many previously non-impacted sites reporting unusually high ozone exposure. Any determination of non-attainment is subject to petition for events (“exceptional events” such as wildfires)

that are beyond the control of the states or counties involved. If 2018 had been similar to 2017 (a year with relatively little wildfire influence), the three-year averages at least two sites (Kenosha Pass, RMNP) would likely not have exceeded the NAAQS.

Of equal importance was the number of long-duration elevated ozone events in 2018. In past years, hazardous concentrations of surface ozone exceeded 48 hours in duration only occasionally (e.g., the early-September event in 2018). Conditions in 2018 were such that ozone posed a threat to vegetation and the well-being of human visitors to USFS lands in many locations.

Elevated ozone in the western US in 2018 was the direct result of ozone precursors emitted during a severe wildfire season. Wildfires played a particularly important role after mid-July, when very large fires in California and Oregon were burning. Additional impacts to central and eastern Colorado sites were created by early-season fires in the southern part of the state. Although area burned nationwide was lower (3.5 million ha) in 2018 than in 2017 (4 million ha), the locations of the fires upwind of or proximate to many of the R2/R4 monitoring sites was critical. Fig. 1 shows the wildfire area in 2017 and 2018, with substantial increases in all upstream states except Arizona and Nevada.

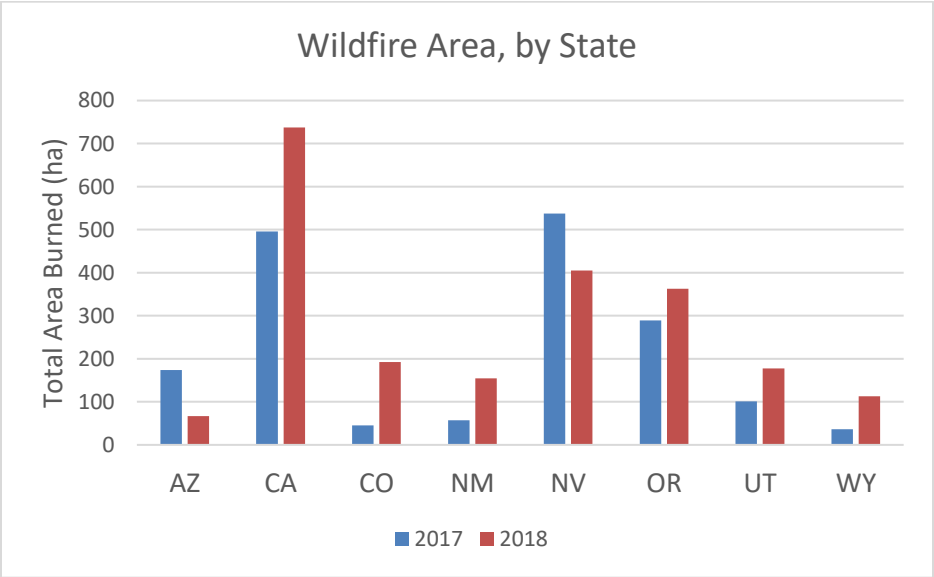

Fig. 2. Wildfire area (ha x 1000) on or upstream of R2/R4, 2017-2018 (source: NIFC).

The year's peak ozone was observed at many Colorado and Utah sites during a regionally-synchronous event in the second week of June. Ozone reached "unhealthy" levels over much of southwestern and west-central Colorado on this date (USEPA 2019). A large source of precursors during this event was the 416/Burro Complex Fire near Durango, Colorado. This fire was the sixth-largest in the state's history and was upwind of nearly all of the network's sites in Colorado. Peak 8-hour ozone concentrations were observed on June 11th during this event at 17 of the 27 sites covered in this report (see Table 2 above). The Spring Creek Fire, in the southeastern part of the San Luis Valley in Colorado and the state's third-largest on record, had moderate impacts on some sites east of the Continental Divide.

Two additional ozone peaks occurred in August, which had their greatest impact at low-elevation sites. These events were most likely the result of historically-large wildfires (particularly the Carr and Mendocino Complex) burning simultaneously in northern California. These fires began in late July and continued to burn through mid-September. In

northern Nevada, the Martin Fire of 176,000 ha burned during most of July and may also have contributed precursors early in this event. Both the Martin and Mendocino Complex fires were believed to be the largest in their respective states' histories. The August events very likely would have produced the highest readings for nearly all the network's sites had they not been eclipsed by the 416 Fire event in June.

Despite the size and severity of the Camp/Woolsey fires in southern California late in the calendar year, none of the sites on the R2/R4 network appear to have been impacted. The MM117 fire, which burned in late April in El Paso County, Colorado and ranks as the state's ninth-largest, also does not seem to have affected any sites.

Cumulative ozone exposure to vegetation (Table 2), quantified by the W126 statistic, was also extraordinarily high during the 2018 monitoring season. The daytime exposure threshold for vegetation tissue damage of 13 ppm-hr was exceeded at all sites monitored except four (Ruby Guard, NV; and Kremmling, Flattops, and Norwood, CO). In addition, several sites (Goliath Peak, Kenosha Pass, RMNP, Shamrock, and Silt-Collbran, CO; Snowbird and Little Mountain, UT) have now averaged over 13 ppm-hr W126 over the past three years (see Appendix for discussion).

IV. Funding.

Funds for this work are provided by Regions 2 and 4, USFS; the Ashley and Arapaho-Roosevelt NFs, and RMRS. A summary of funding is provided in Table 3 below:

Source	Jobcode	Allocated, FY18	Expended	Balance, end FY18
Region 2	NFMG16	$20000	$9223	$10767
Region 2	NFMP16	10000	7837	2163
ARNF	NFVW10	5000	3396	1604
Ashley NF	NFMP01	1910	1319	591
RMRS	FRRESA	8016	8016	0
Total		$44926	$29791	$15125

Table 3. Funding sources, expenditures and remaining balance, ozone data collection and analysis, FY18

The line for RMRS incorporates three pay periods of salary, an approximation of time needed to complete data QC and analyses.

Item	Amount	Percentage of Total
Salary	$21376	72
Travel	3368	11
Vehicle Mileage	420	1
Parts/Equipment	4354	15
Contract Repairs	282	1
Contract Services	0*	0

Table 4. Expense categories and percentage of total expenditures

*Upload of 2018 ozone data to AQS was covered by FY19 funds.

V. Acknowledgments:

RMRS personnel are grateful for the assistance of site operators Brian Murdock (Manti-LaSal NF), Helen Kempenich (retiree volunteer), Chris Plunkett (Ashley NF), Ryan Buerkle (Ashley NF), Beau Uriona (NRCS) and Andrea Holland (retiree volunteer). Their efforts result in increased efficiency of this project and considerable cost savings. RMRS also thanks Greg Harshfield, Clyde Sharp, and Bret Harkwell, Air Quality Division, CDPHE, for their efforts to conduct audits at many of the RMRS sites.

VI. Literature Cited:

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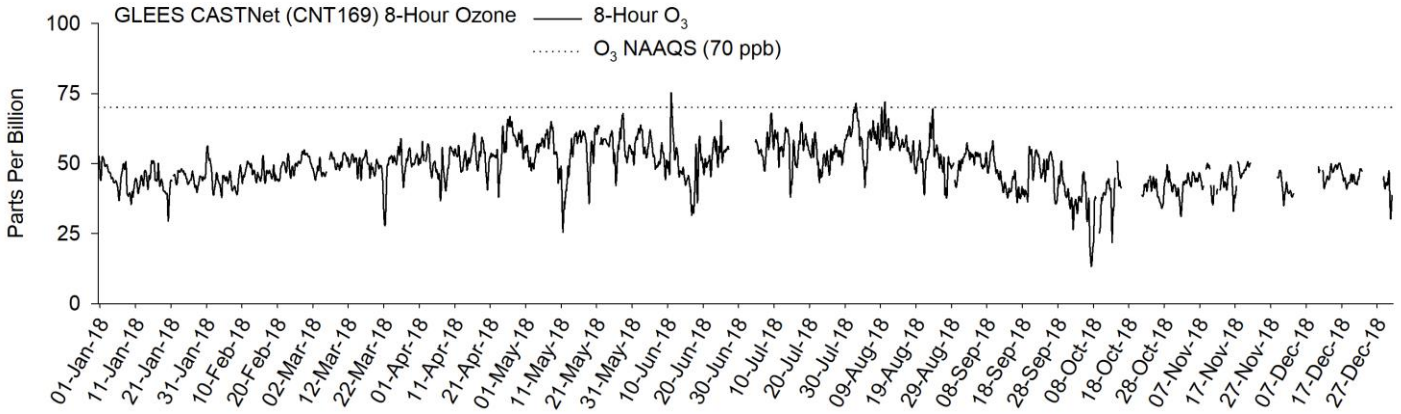
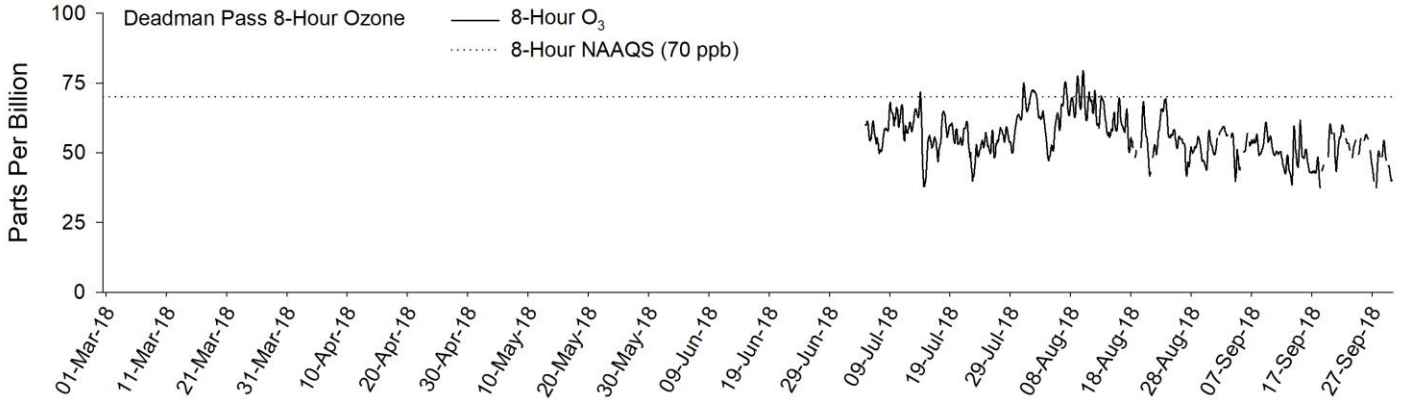
Appendix A. Individual Site Data and Discussion.

Region 2 Sites.

1. Centennial. The RMRS-operated Centennial CASTNet site experienced four days during which the 8-hour average readings exceeded 70 ppb, an unusual occurrence for this site which is remote from urban and industrial precursor sources. However, the peak event on June 11th was of relatively short duration (18 hours O_3>60 ppb). Of greater significance, in terms of vegetation hazard, was the period August 9th-17th, when ozone averaged over 60 ppb for the entire period.



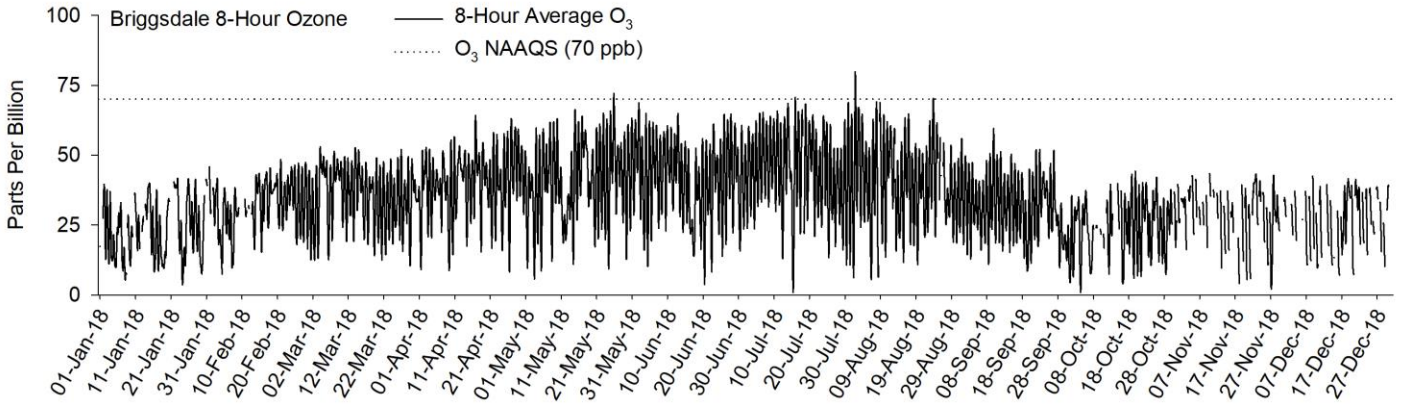
2. Deadman Pass. Initiation of monitoring at Deadman was again delayed by difficulty of access over Deadman Pass Road, and the season's peak ozone was likely not observed. However, the data collected indicate significant impact from the August wildfire-induced ozone event, with 1st-maximum (79.3 ppb) and 4th-maximum (75.0 ppb) occurring during that event. The event had a greater impact at Deadman than at its neighboring site to the north, Centennial, with ozone averaging over 65 ppb for the duration. Late August saw a shorter, lower-amplitude event.



Cumulative ozone exposure (15.8 ppm-hr), although measured for only one 3-month period in 2018 (July-September), is among the highest of the network's sites for this period. RMRS continues to work on methods to capture earlier-season data at this remote site.

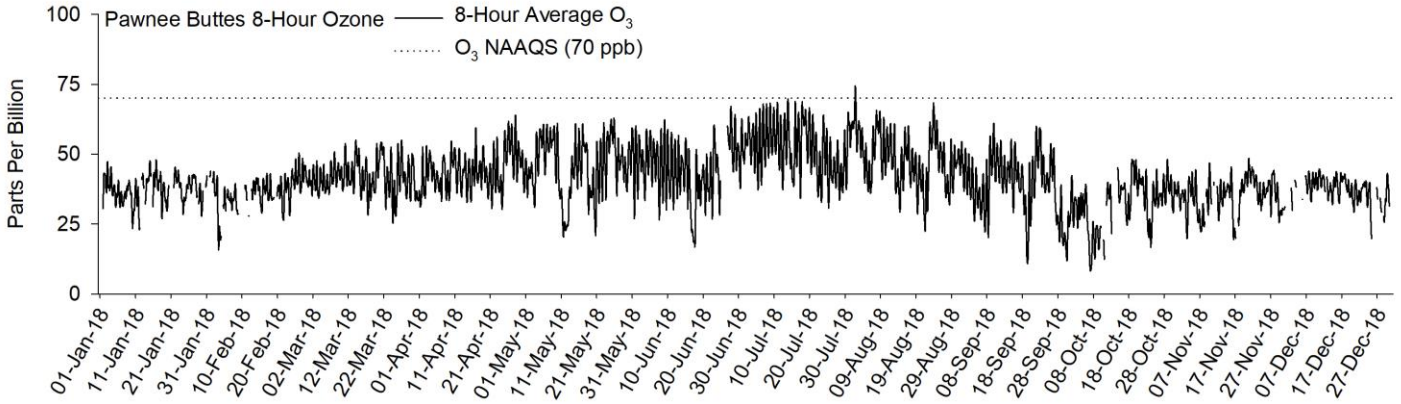
3. Briggsdale. Average (8-hour) ozone at the Briggsdale work facility on the Pawnee NG reached 79.8 ppb on August 2nd, corresponding with the California wildfire event. This year's 70.3 ppb 4th-maximum figure, occurring in late August, averaged with 2016 and 2017 data at 66.7 ppb, falls below the limit allowed under the 2015 NAAQS. (The three-year

average would likely be higher if it were not for equipment failure during peak ozone in summer of 2017.)



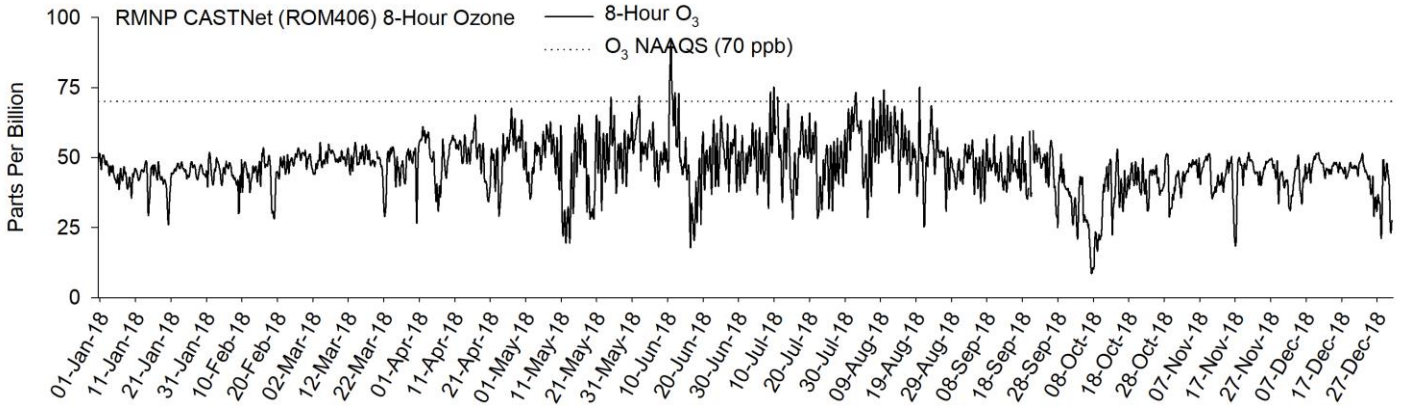
Briggsdale was one of the few Colorado sites not heavily impacted by the 416 Fire. No long-duration (>24 hrs) events occurred in 2018. Such events are rare near in the Briggsdale area as ozone is well-titrated at night by urban NO_x emissions. However, mid-July saw three consecutive days where hourly averages reached or exceeded 69 ppb, and 68 days in between mid-April and late August saw averages of 60 ppb or greater. The highest 3-month W126 figure (June-August) was 16.9 ppm-hr, consistent with the frequency of >60 ppb ozone.

4. Pawnee Buttes. Ozone observations at the Pawnee Buttes site paralleled those at Briggsdale, with a period of several days in mid-July with peak readings near 70 ppb, and a peak event on August 2nd. As in past years, Pawnee Buttes was slightly less impacted Briggsdale (1.1 ppb lower daytime average). This site's three year average of 4th-maxima (63.9 ppb) would not justify nonattainment designation.



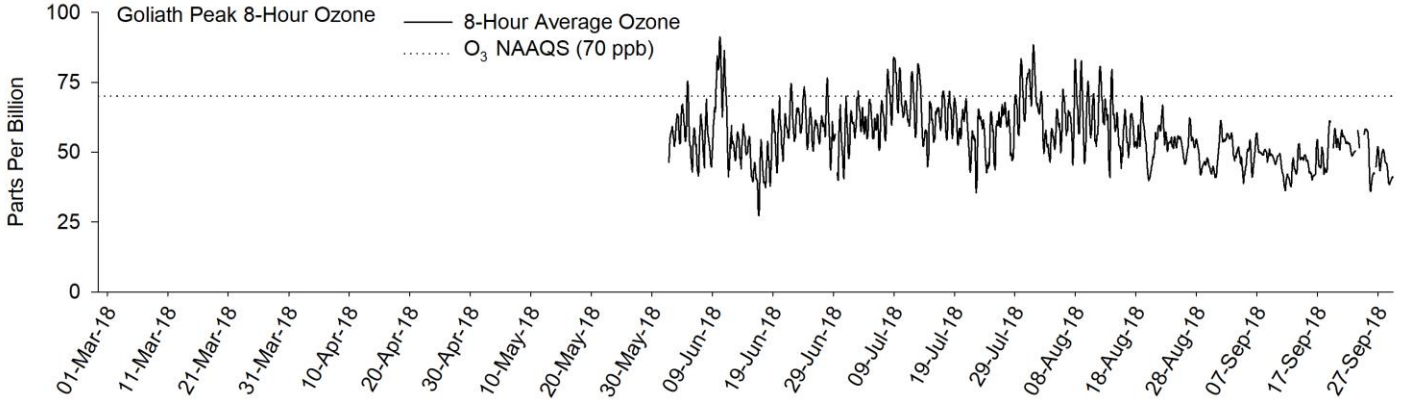
W126 at Pawnee Buttes (15.4 ppm-hr, June-August) was also marginally lower than that observed at Briggsdale. This is the second-highest figure on record (higher only in 2013).

5. Rocky Mountain National Park CASTNet. RMNP had one of its worst ozone years on record, with 8-hour averages dramatically peaking (1st-maximum of 91.8 ppb) on June 11th during the 416 Fire. The site also recorded a maximum one-hour average reading of 97.0 ppb on the same date. Remarkably, during the 19 days from July 30th to August 17th, one-hour ozone averages exceeded 60 ppb on every day except one. Minor events also occurred in the second half of April. The 4th-maximum value was recorded on August 10th (74.1 ppb). RMNP's three-year average of 4th-maxima (70.3 ppb) exceeds the 2015 NAAQS.



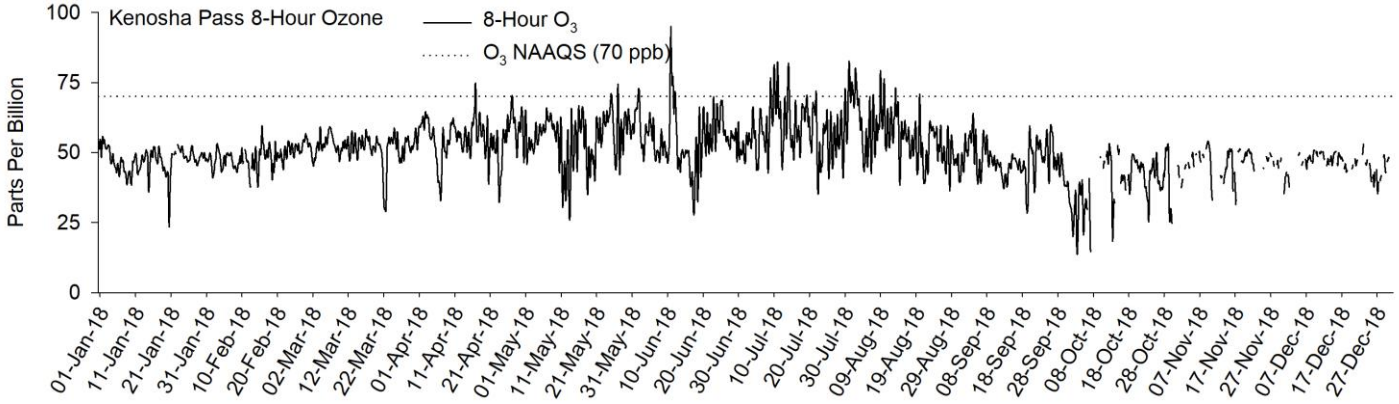
W126 calculated for the RMNP CASTNet, at 18.1 ppm-hr, was (surprisingly) not among the highest figures for the site, and is somewhat lower than those observed in the high ozone years of 2010-2013. However, ozone impacts at RMNP (and on the Front Range generally) continue to be noted and have even made appearances in mass media (*Estes Park Trail*, 2018).

6. Goliath Peak. This site's 1st-maximum 8-hour value, at 91.2 ppb (June 11th) is the third highest of all sites. The three-year average of 4th-maxima (76.3 ppb) is highest, and with this, Goliath also joins the group of sites with the dubious distinction of being in violation of the 2015 NAAQS. Lengthy periods of elevated ozone characterized the season at Goliath. The first week of July featured a five-day period with ozone averaging just under 70 ppb; the Spring Creek Fire may have been a contributor to this event. Additional wildfire events produced periods of elevated ozone (July 31st-August 3rd averaging 74.0 ppb; and August 9th-14th averaging 65.8 ppb). Several other shorter, less severe events also occurred throughout the summer. Readings of over 80 ppb were common. In most years, Goliath may experience peak ozone in springtime, outside the window of the usual RMRS observation season. However, at nearby Kenosha Pass (see 7. below), only minor events were observed before June, thus, work at Goliath this year likely captured the most important data.



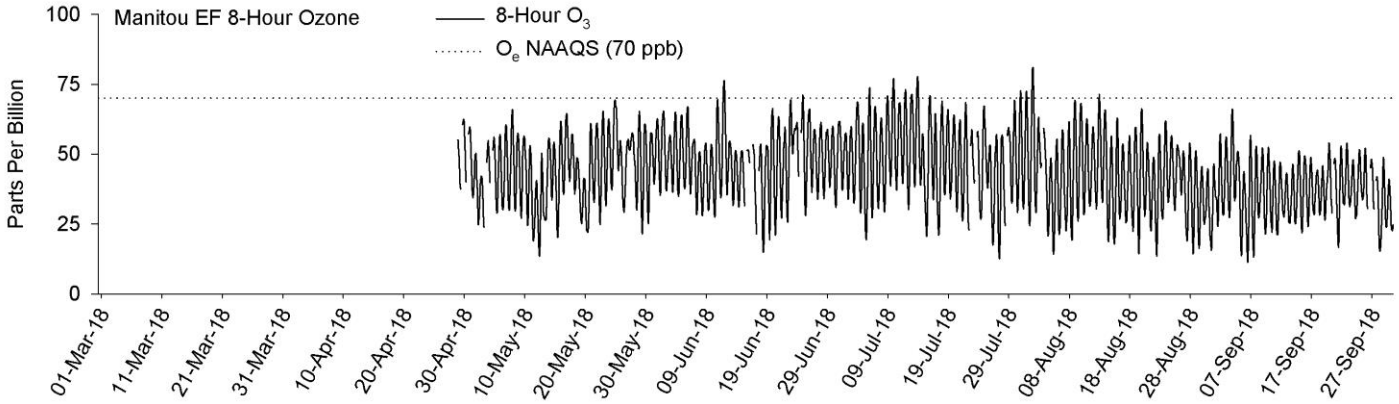
In contrast to the site's lowest-ever W126 figure in 2017, this year's (26.2 ppm-hr, June-August) was second-highest on the network for 2018 and has been exceeded at Goliath and other sites only a few times since data collection began. The dominant tree species at this site, Rocky Mountain bristlecone pine, is known to be more robust to high ozone exposure than other coniferous species (Townsend & Dochinger 1982) and likely is resistant to events such as those that occurred in 2018. However, less-tolerant species at lower elevations (e.g., ponderosa) may be exposed to similar levels and may incur toxicity. This issue may also be present on much of the Front Range forest lands, given the ozone observations at RMNP (see 5.above) and Kenosha Pass (see 7. below).

7. *Kenosha Pass*. The highest 1st-maximum value on the network in 2018, 94.9 ppb, was observed at Kenosha, and secured its fourth-highest ranking on the 3-year average NAAQS exceedance list at 72.5 ppb. The same events that heavily impacted Goliath also were observed at Kenosha, with similar amplitudes and durations. Several minor ozone events occurred in spring.



Cumulative exposure at Kenosha Pass (23.9 ppm-hr, June-August) is third-highest on the network, and is similar to the much higher values observed at the site in the early 2010s. By the indications of Kenosha, Goliath, RMNP and Deadman, vegetation on Front Range forest lands should be monitored for signs of ozone damage.

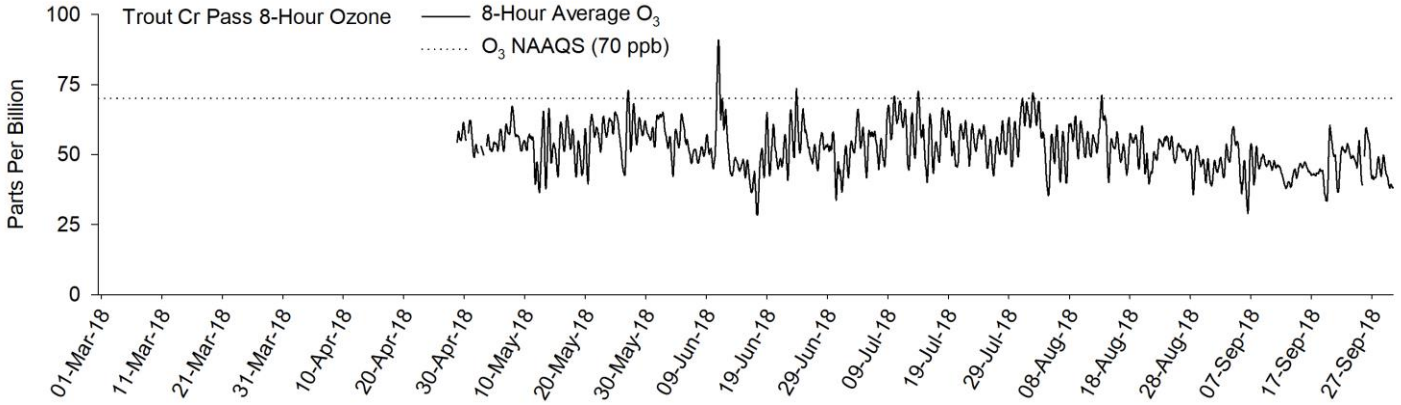
8. Manitou Experimental Forest. This site was operated for 2018 at the request of CDPHE, who were conducting a high-resolution study of surface ozone in the Colorado Springs area. As of this writing (September 2019), their findings had not yet been released. Like much of the rest of the Front Range, ozone reached hazardous levels at Manitou. First-maximum 8-hour average ozone was 81.0 ppb (August 2nd), and the 4th-maximum value was observed on June 12th. July 9th-14th saw the most significant long-duration event, where ozone exceeded 70 ppb each day. Manitou's location placed it downwind of the Spring Creek Fire at times and this fire may have affected readings in mid-July.



Highest W126 observed was 21.7 ppm-hr (June-August), considerably higher than values observed when ozone was last monitored at this site in 2008-2010.

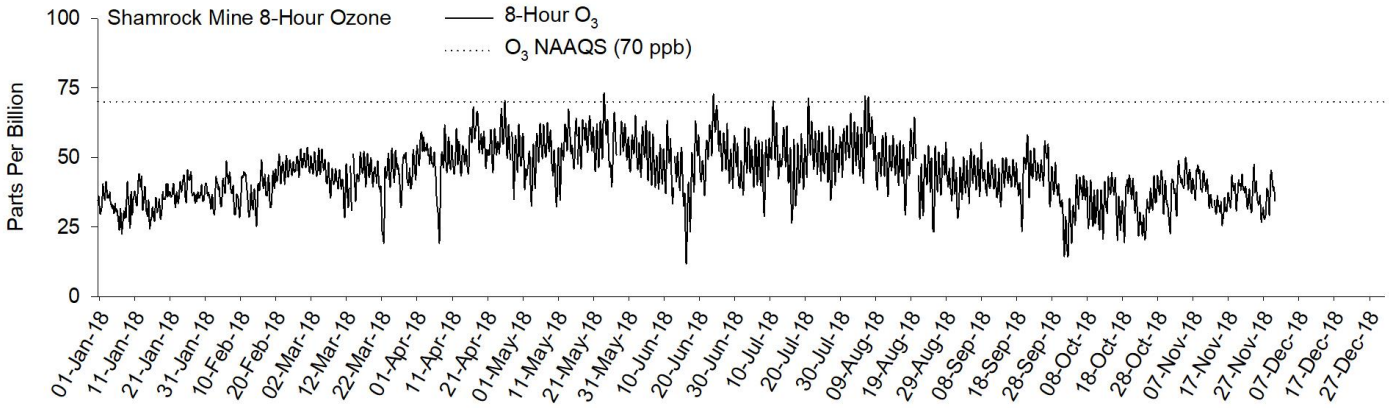
8. Trout Creek Pass. The substantial impact of wildfire on ozone in 2018 is nowhere more evident than at this site. Ordinarily one of the least-impacted sites on the network, average daytime ozone (55.3 ppb) was more than 17 ppb higher this year than in 2017, and was actually slightly higher than the urban-influenced Manitou EF site. The site's location with respect to prevailing wind patterns and the geography of the 2018 wildfires combined to create the

highest ozone concentrations observed at Trout Creek Pass since monitoring began. As at many other Colorado sites, the 416 Fire elevated ozone in mid-June, and the California fires had some effect in early August. However, at Trout Creek, high ozone levels were also observed in early June, when the nearby Weston Pass Fire was burning, and in mid-July during the Spring Creek Fire. The 1st-maximum figure for Trout Creek Pass, 90.8 ppb, occurred during the 416 Fire and is nearly equal to that of Goliath.



Frequent readings over 60 ppb contributed greatly to the site's 19.0 ppm-hr mark for cumulative exposure. Although a number like this would usually be cause for concern, the site's history of negligible ozone hazard suggests that impacts in 2018 were unique, and hopefully not to be repeated soon.

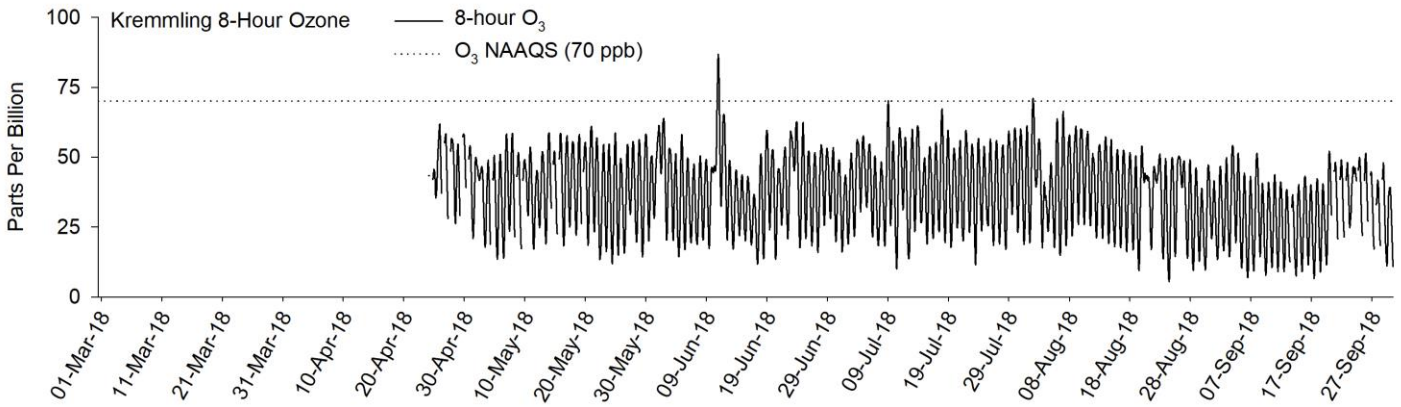
9. Shamrock. This site seems to have escaped the strongest impacts from the 416 Fire; in mid-June, when many other sites were recording their highest readings of the year, Shamrock had a brief period of unusually low readings. April and May events produced the year's highest readings (1st-maximum 73.1 ppb, May 24th; 4th-maximum 71.7 ppb, August 7th), while a series of short-duration events spaced over the summer produced other periods of elevated ozone.



Shamrock's 3-year, 4th-maxima average of 67.8 ppb puts it in compliance with the 2015 NAAQS. As was the case at Trout Creek Pass, the W126 figure of 16.1 ppm-hr will likely prove to be anomalously high.

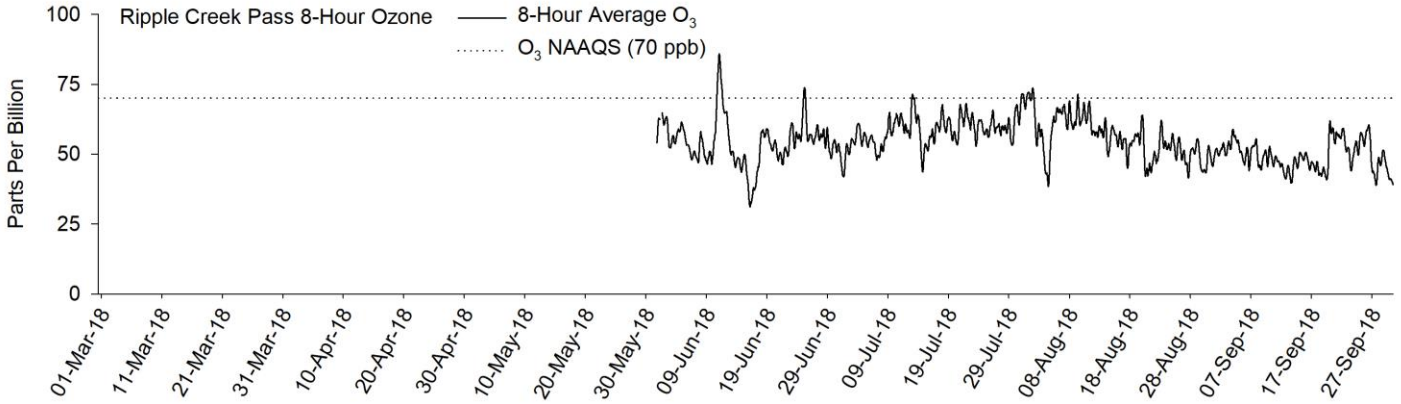
10. Kremmling. This was the least-impacted site in the 2018 monitoring season, with the lowest daytime average ozone (49.0 ppb), the lowest overnight average (25.3 ppb due to urban-source scavenging), and the lowest W126 figure at 10.6 ppm-hr. The 416 Fire event did produce a distinct spike in ozone on June 11th, with the 1st-maximum value registering

86.8 ppb. However, the three-year 4th-maximum average (62.4 ppb) remains below the 2015 ozone NAAQS.



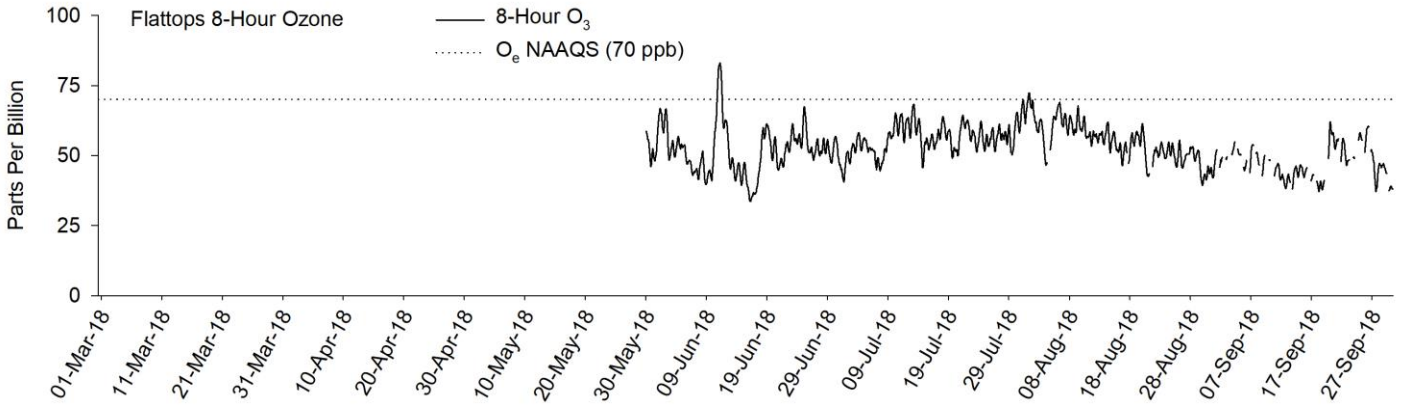
Two minor, short-duration events took place in mid-July, and the California fires produced a brief spike in early August. Otherwise, ozone remained well below hazard threshold.

11. Ripple Creek Pass. The 416 Fire event produced a period of nearly 48 hours when ozone was above 60 ppb, and averaged 72.3 ppb. The 1st-maximum value was also observed during this time, at 85.9 ppb. It was not possible to calculate the three-year average 4th-maximum due to inadequate data in 2016, but data from nearby sites suggest that Ripple Creek Pass would likely have remained under the NAAQS. Other, less-severe events followed in late June and mid-July, and the California wildfire event produced two periods of elevated ozone. From July 30th to August 2nd, ozone averaged just under 70 ppb, and the period August 5th-12th saw ozone exceeding 70 ppb each day and averaging 64.1 ppb for the week. Both of these long-duration events represent potential hazards to vegetation.



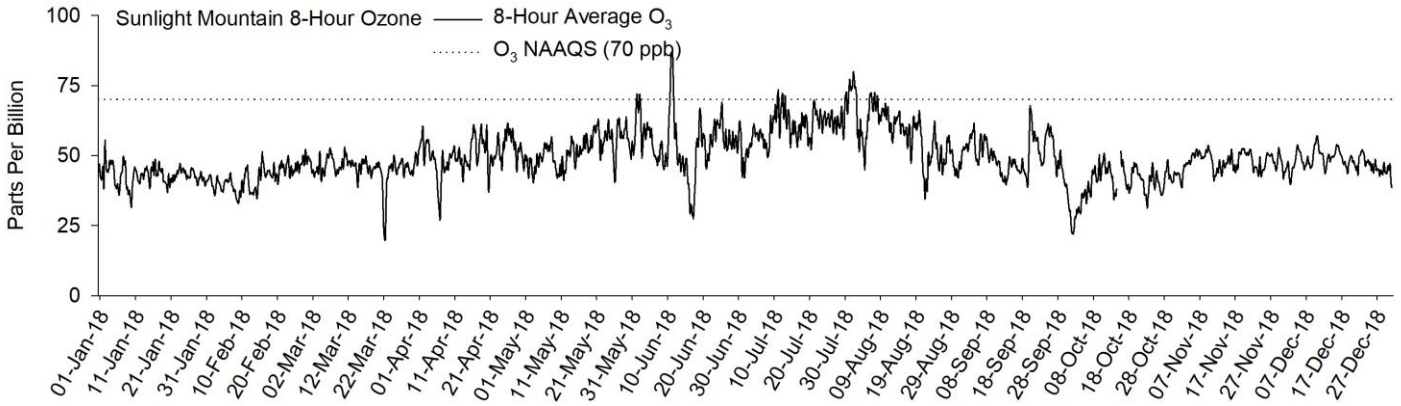
These hazards are reflected in the June-August W126 figure of 16.7 ppm-hr. This is the highest figure on record for the site and is well in excess of its usual <10 ppm-hr W126 values.

12. Flattops. With Ripple Creek Pass, this site monitors ozone impacts to the Class I Flattops Wilderness. Although the 416 Fire event produced a period of elevated ozone equal in duration to that seen at Ripple Creek Pass (about 48 hours), the magnitude was significantly less (average 69.0 ppb). Impacts of subsequent events during the summer were also less severe than at the neighboring site. The 1st-maximum 8-hour figure was 83.1 ppb (June 11th), and the 3-year average of 4th-maxima was 64.8 ppb. As is the case at other remote, high-elevation sites, the 2018 4th-max figure is not typical.



The lower magnitude of the mid- and late-summer events limited cumulative ozone exposure to 11.8 ppm-hr (June-August), higher than in most years at Flattops, but below the vegetation hazard threshold.

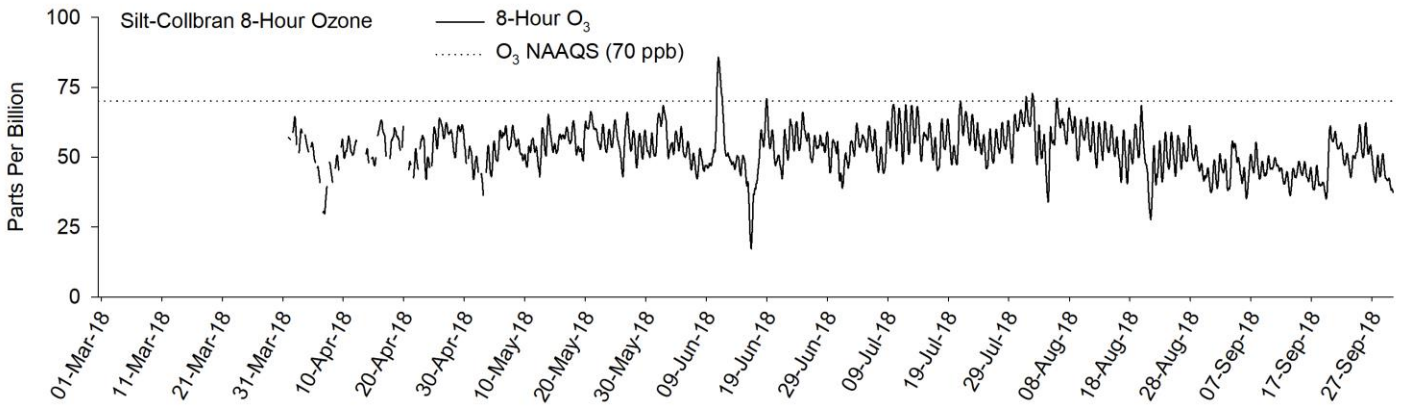
13. Sunlight Mountain. Sunlight experienced impacts from the same wildfire events that affected surrounding sites, but at somewhat lesser severity. This may be due to the well-mixed nature of the site, which allows rapid dispersion of pollutants. Sunlight's 1st-maximum value was recorded on June 11th (86.8 ppb), and the 3-year average of 4th-maxima is 68.7 ppb. This figure is influenced somewhat by 2016's anomalous high-ozone event in December of that year. Other running averages of 4th-maxima (e.g., 2013-2015) would result in lower values.



W126 (highest was 18.4 ppm-hr, June-August) indicates less cumulative ozone impact than at many sites in 2018. This figure is appreciably higher than recent low-ozone years, but still much lower than observations in 2010-2012.

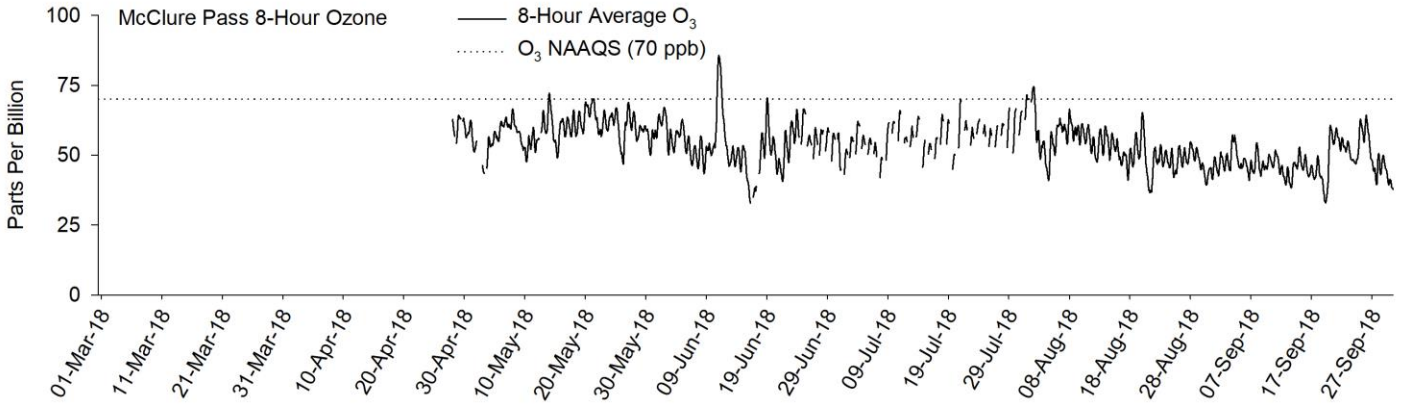
14. Silt-Collbran. Peak ozone readings over 80 ppb occurred during the June 11th wildfire event, but the period of elevated readings was fairly brief (>60 ppb for 29 hours). This was long enough, however, to produce a 1st-maximum 8-hour average of 85.9 ppb. An extended period of high ozone occurred from July 9th through August 3rd. Although ozone averaged only 58 ppb during this time, it exceeded 60 ppb on every day except two and typically peaked in the mid-60s to low 70s ppb. This event also produced the site's 4th-maximum reading (70.9 ppb, August 6th). Silt-Collbran's 3-year

4th-maxima average remains below the NAAQS, at 67.5 ppb



Cumulative ozone exposure at Silt-Collbran has been variable over the eleven years of monitoring. This year's peak figure of 19.2 ppm-hr (June-August) was exceeded only in 2011. Despite this year's figure, vegetation damage is not expected in the vicinity of the site.

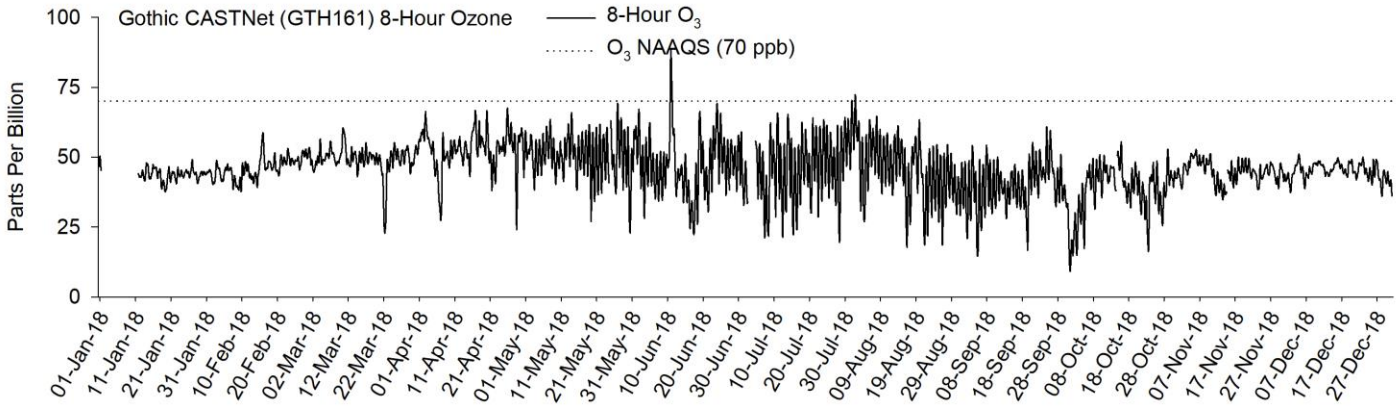
15. McClure Pass. Data collection was impaired by battery failure June 16th through August 4th, and was limited to hours of daylight when the instrument was able to run on solar power. Because of this, full evaluation of the summer's wildfire impacts wasn't possible. The three-year average of 4th-maxima at this site is 65.8 ppb. The 1st-maximum value for 2018 occurred on June 11th, at 85.7 ppb. Two minor periods of elevated ozone occurred in May, with the two wildfire-influenced spikes (mid-June and early August) also noted, as at other sites.



The W126 value of 17.6 ppm-hr was measured in the May-July period, indicating stronger impact from early-season ozone here than at many other stations. This figure is a departure from the previous ten years, during which W126 has never exceeded 11.2 ppm-hr. Barring another serious wildfire season, cumulative ozone exposure is expected to return to low levels.

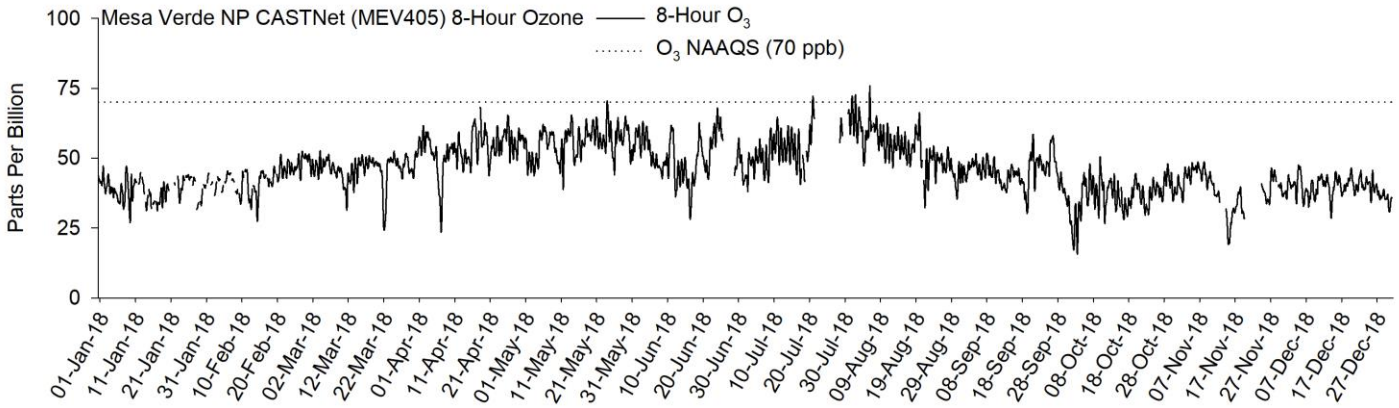
16. Gothic CASTNet. Only two high-ozone events affected the Gothic CASTNet site in 2018, the June 11th and early-August events common to most Colorado sites. Neither event was of long duration at this site. Unlike many years, 2018 did not see a spring ozone peak at Gothic, although several minor events occurred in April and May. The high 1st-maximum for 2018 (88.9 ppb) occurred during the 416 Fire. Gothic's 3-year 4th-maximum average (65.8 ppb) for 2016-

2018 is below the NAAQS.



In 2007, the 3-month W126 measured at Gothic was 15.3 ppm-hr (April-June); this year's figure of 15.6 ppm-hr is the highest since then. Despite the June spike in ozone, this is not far outside the 8-13 ppm-hr numbers seen in years past.

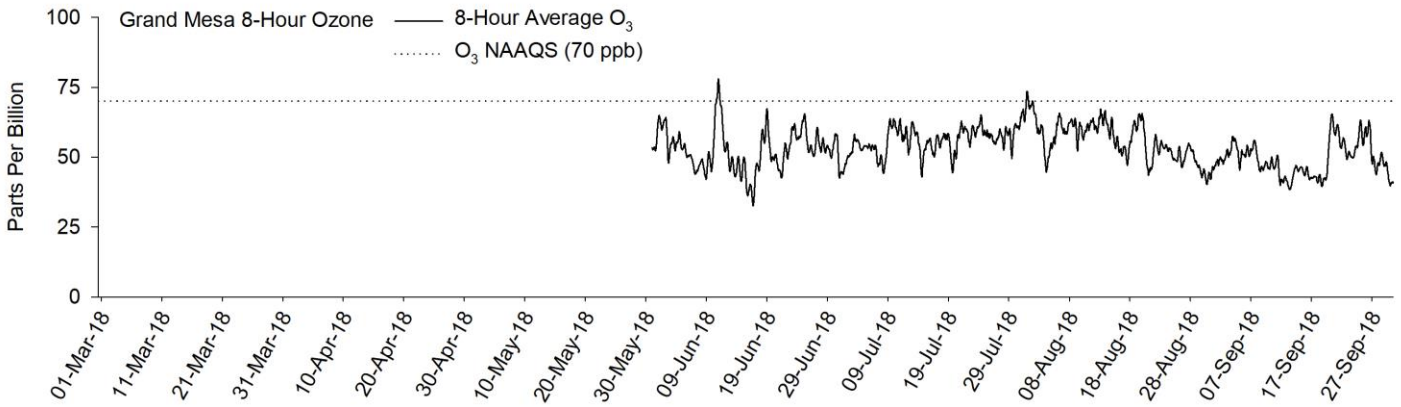
17. Mesa Verde CASTNet. Mesa Verde National Park was somewhat unique in that it was a Colorado site not heavily affected by the 416 Fire. It was apparently protected from the voluminous precursor emissions that impacted areas east and north. The site's highest readings, including the 75.9 ppb 1st-maximum, came during the California wildfire event on August 6th. The first eight days of August were an extended period of ozone readings, with concentrations exceeding 60 ppb each day. The average for this event was 61.8 ppb. Ozone was otherwise fairly benign at Mesa Verde, with only a few brief episodes approaching hazardous levels.



Last year's W126 mark, 14.7 ppm-hr, was second-highest on the network; this year's figure of 13.5 ppm-hr (April-June) is one of the lowest on the network in 2018. However, data losses in summer limited the utility of W126 assessment in 2018.

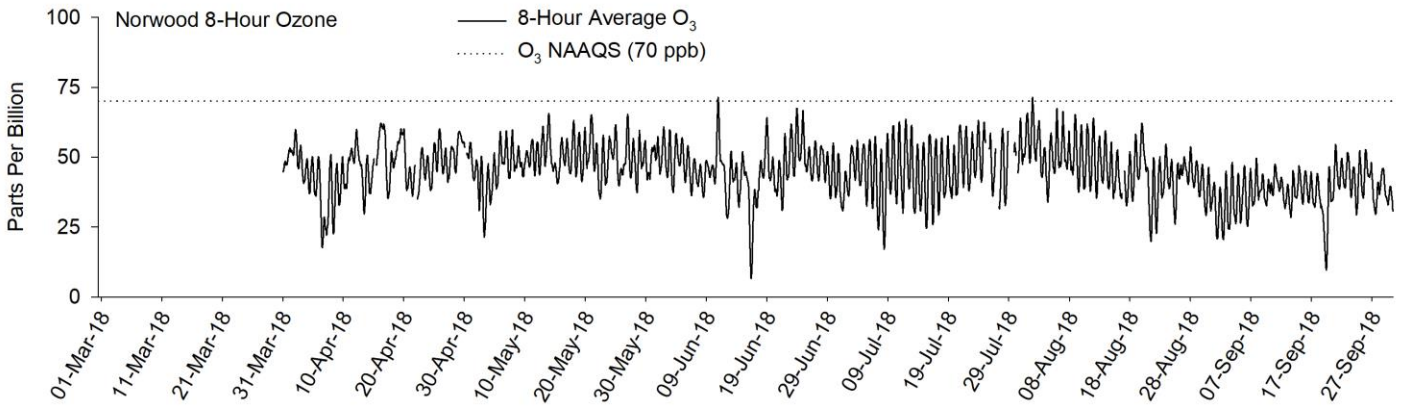
18. Grand Mesa. Another relatively un-impacted site in 2018 was Grand Mesa. 416 Fire-sourced ozone reached the site in June, but the peak here (1st-maximum 78.0 ppb) was short-lived and lower than many other sites. Grand Mesa also seems to have escaped the worst of the fire events later in the season, with only a brief, modest spike noted in early

August.



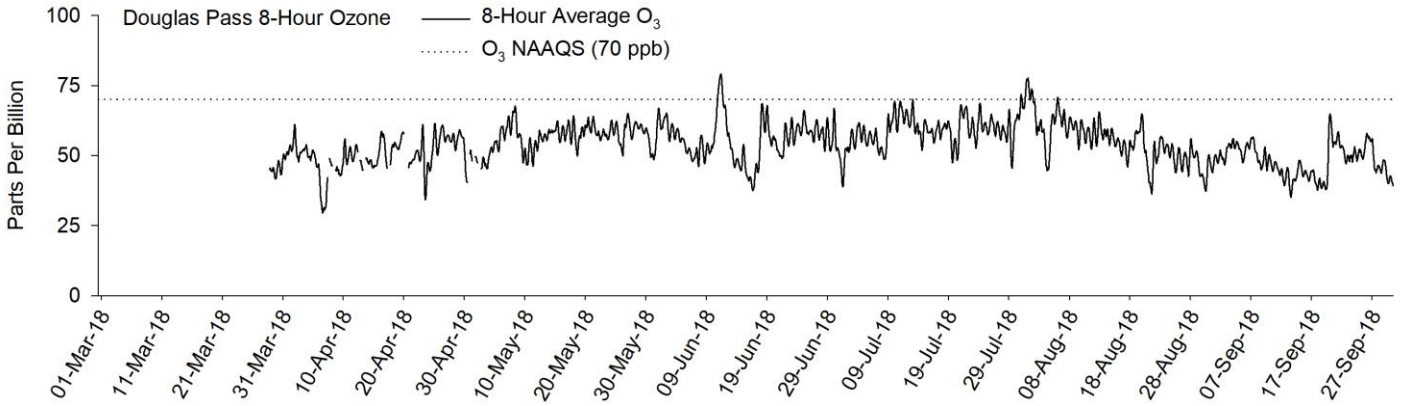
Cumulative ozone exposure at Grand Mesa continues to be well below network average, but recorded one of its higher 3-month averages this year (13.9 ppm-hr, June-August). In the context of several years of low cumulative metrics, this number does not suggest a vegetation hazard.

19. Norwood. Ozone at Norwood in 2018 fits the pattern of far West Slope sites missing the hefty loading of sites in central and eastern Colorado. The eight-hour average during June event barely exceeded 70 ppb, although that event did produce the season's highest eight-hour reading (71.4 ppb). The longest episode of elevated ozone, July 30th-August 3rd, averaged 57.0 ppb, a much less emphatic event than elsewhere on the network.



W126 peaked at 12.4 ppm-hr in the June-August period, below hazard level and consistent with low cumulative ozone exposure in years past.

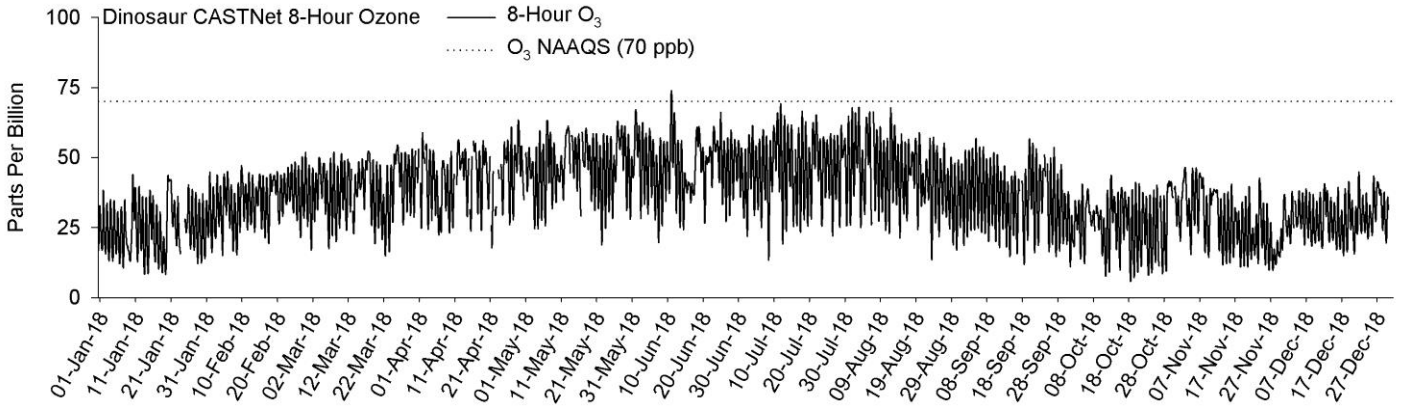
20. Douglas Pass. June 11th-12th was the period of peak ozone at Douglas Pass, with the reading never dropping below 60 ppb during the 48-hour period. This event also recorded the year's 1st-maximum at 79.1 ppb. Despite this, the site's 3-year 4th-maxima average is under the NAAQS, at 67.0 ppb. The mid-July and early August events noted elsewhere were also evident at Douglas Pass. The 72 hours from July 31st to August 2nd saw ozone average 70.1 ppb at Douglas, with no readings under 60 ppb.



The August event, and lower-amplitude long-duration events in July, contributed to a W126 figure of 18.3 ppm-hr (June-August), the highest observed yet at the site. The May-July metric was only slightly lower, and both marks are substantially higher than past observations.

Region 4 Sites.

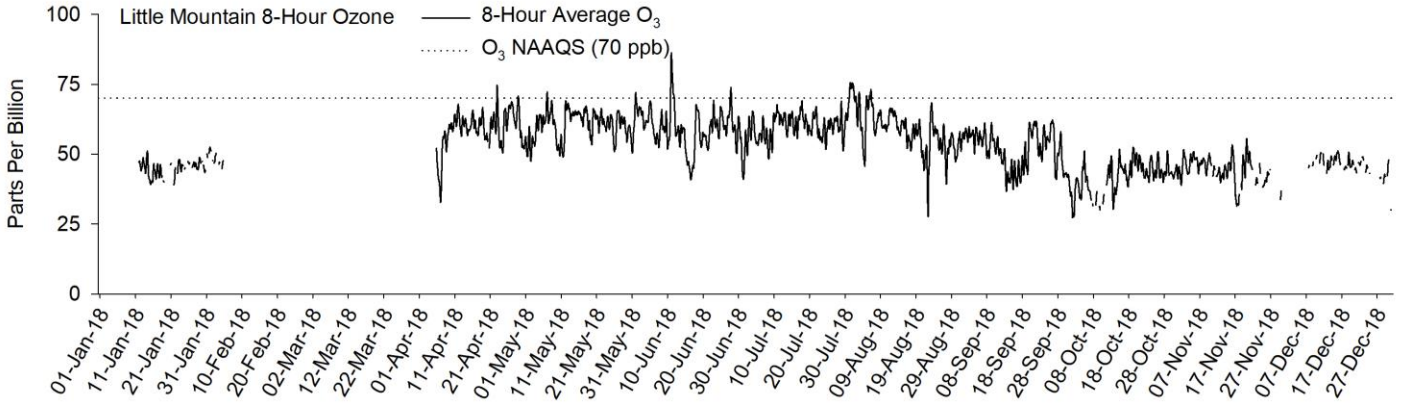
21. Dinosaur CASTNet. Located at the eastern end of the Uintah Valley, adjacent to Dinosaur National Monument, this site is within the Uintah Basin nonattainment area. However, in 2018, the site seems to have been insulated from the ozone hazard presented elsewhere in the area (see 22. Little Mountain, below). This year's 4th-maximum, 67.8 ppb, is substantially lower than in 2016-2017, and the 1st-maximum reading (73.9 ppb) highlighted the only event in 2018 during which the 8-hour average exceeded 70 ppb. The site's three-year average, however, remains well above the NAAQS at 72.5 ppb.



The absence of long periods of elevated ozone at Dinosaur kept the W126 figure at 14.5 ppm-hr, a relatively low figure compared to other sites in 2018.

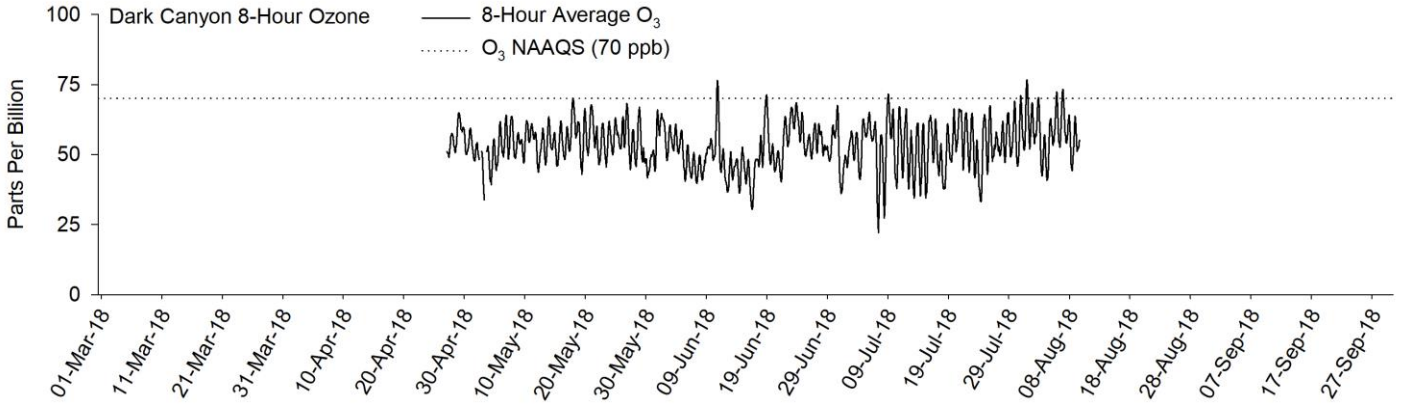
22. Little Mountain. The site's analyzer failed in early February, and replacement was not possible (due to difficulty of access) until early April. Power-supply issues also limited late-year data collection. Despite these problems, data are adequate to assess 2018 ozone here. Little Mountain is the northwestern-most site to be affected by the June 11th event, peaking at 96.9 ppb (hourly) and recording a 1st-maximum on that date of 86.3 ppb; the 4th-maximum of 74.6 ppb was observed on August 2nd. Most of Uintah County was determined to be in nonattainment of the 2015 ozone NAAQS, and a recent document (USEPA 2017) contains much information on the geography, topography and meteorology of the ozone problems experienced in the area. In previous years, the Little Mountain site had not been heavily impacted; most

of the ozone pollution in northeastern Utah was confined to the lowest 300 m of the atmosphere by temperature inversions. This year, high ozone levels were recorded at much higher elevation than in years past.



Eight-hour ozone averages peaked during the June 11th event (33 hours, 75.2 ppb average) and July 29th through August 3rd saw ozone continuously at or above 60 ppb, averaging 68.6 ppb for 107 continuous hours. Both of these events were of sufficient duration to have had some vegetation impacts. Other, lower-magnitude events occurred in late April and May. Cumulative exposure (24.5 ppm-hr May-July) unprecedented at this site and is third-highest on the network this year.

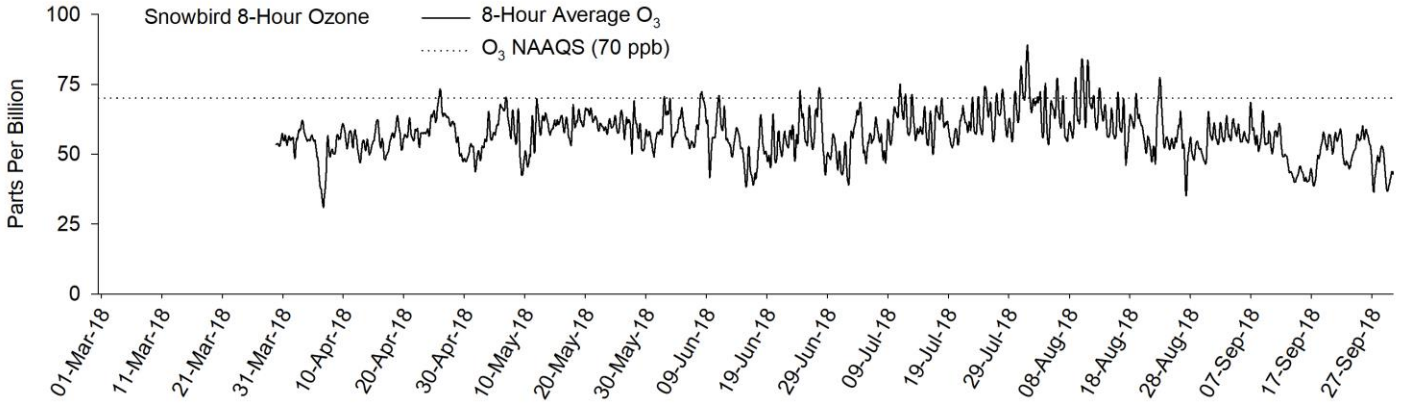
23. Dark Canyon. The region-wide bad air of mid-June also affected the network's southwestern-most site in 2018, although, as at other sites west of Colorado, the peak (1st-maximum of 76.6 ppb, June 11th) was short-lived (12 hrs over 60 ppb) and of limited impact. California wildfire emissions produced a more significant event in early August, with ozone exceeding 60 ppb on most days from mid-July through early August. A datalogger malfunction terminated data collection on August 10th.



Dark Canyon has been among the least impacted by surface ozone since the inception of monitoring in 2014, with 3-month W126 values consistently less than 10 ppm-hr. In 2018, the May-July figure of 19.9 ppm-hr is the highest observed at the site. The June-August W126 would very likely have exceeded this, but could not be calculated because of the datalogger malfunction.

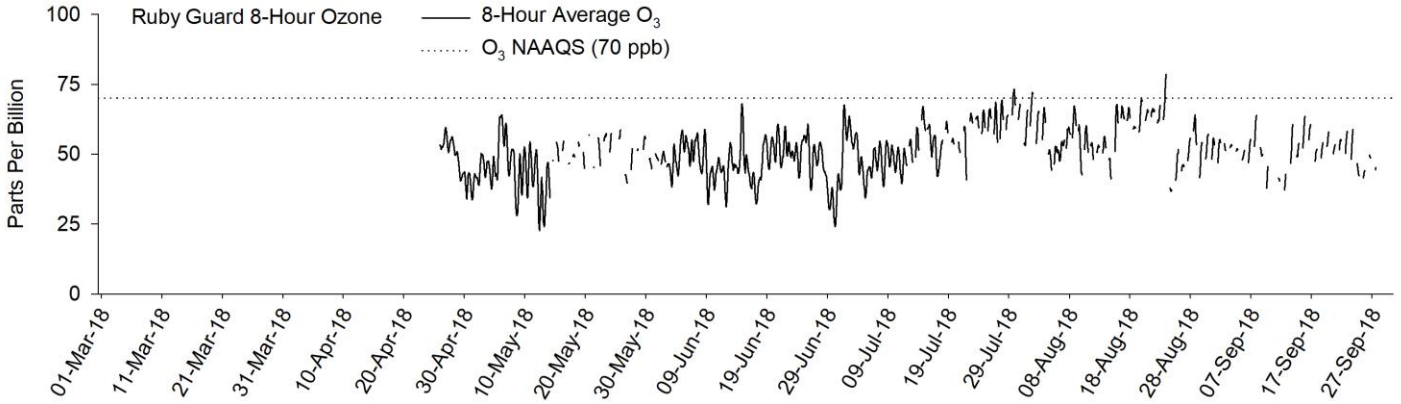
24. Snowbird. Greatest ozone impact on the network was again seen at Snowbird in 2018, reflecting the influence of the heavily-urbanized Wasatch Front. The site was not impacted by the elevated ozone observed elsewhere in mid-June, but the site received sufficient urban-source precursors that the effects of relatively minor short-term events may have been masked. The EPA's nonattainment assessment (USEPA 2017) includes a detailed analysis of how the area's meteorology

and geography contribute to boundary-layer stagnation. Not surprisingly, the site's 3-year 4th-maxima average, at 74.9 ppb, is the second-highest 2016-2018 figure on the network, and exceeds the NAAQS. The site is included in the nonattainment area recently designated for the Wasatch Front by USEPA.



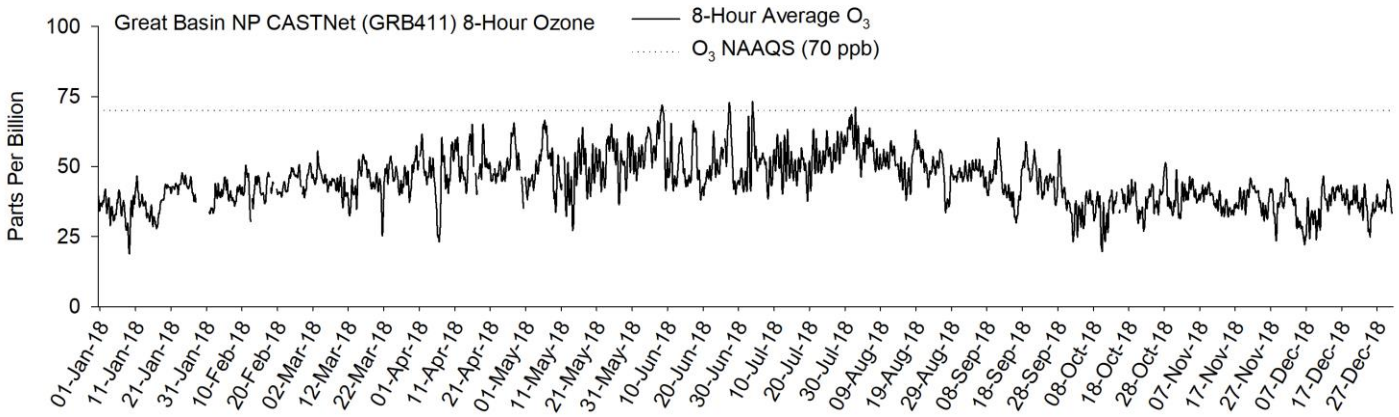
Although it recorded only the third-highest 8-hour 4th-maximum on the network (81.4 ppb, July 31st), the 3-month W126 mark of 27.4 ppm-hr is the highest in 2018, well in excess of the site's previous record of 20.6 ppm-hr (April-May 2014). The rolling 3-month average of W126 here in 2018 was 24.0 ppm-hr, reflecting an environment of almost continuous hazardous exposure. The period from late July through mid-August was the most heavily impacted, with ozone averaging 64.2 ppb for the period, and peaking July 29th-August 2nd, a 112-hour period when ozone never dropped below 61 ppb and averaged 71.2 ppb. The length and amplitude of these events suggest significant potential for vegetation damage downwind of the Wasatch Front urban area.

25. Ruby Guard. The Ruby Mountains experienced two short-duration events early in the season (June 15th and July 2nd), but was more heavily affected during the late-July to mid-August period that impacted all of the network's sites. August 24th was the date of highest readings (1st-maximum of 78.5 ppb), after which ozone significantly declined for the remainder of the monitoring season.



The June-August W126 of 12.3 ppm-hr makes Ruby Guard one of the few sites not to have experienced an extended period of ozone high enough to pose a vegetation hazard.

26. Great Basin National Park CASTNet. Minor, short-duration ozone events occurred throughout late spring at GBNP, with the year's highest observed on July 4th (8-hour 1st-maximum of 73.3 ppb). Another spike occurred in early July, and wildfire emissions again increased ozone in early August, although not to the same extent as was seen at other sites. As in years past, ozone impact was largely absent at the site for much of 2018.



The highest 3-month W126 (13.9 ppm-hr, May-July) was relatively modest in comparison to other sites, and occurred earlier in the year than elsewhere.